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HEART RATE RESPONSE TO VARIED INTENSITIES OF TRAINING

by

© GEOFFREY NEALE MOLLOY

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The undersigned certify that they have read and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Heart Rate Response to Varied Intensities of Training", submitted by Geoffrey Neale Molloy in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

Employing the Astrand-Ryhming nomogram for the prediction of aerobic capacity, it was the purpose of this study to determine the heart rate response to varied intensities of training.

Twenty-four male students aged 17-24 participated in one of four equal groups. Three of the groups underwent a six week training programme consisting of a thirty minute bicycle ergometer ride, three times per week. The remaining group acted as a control. The subjects in each training group trained at a work intensity corresponding to a predetermined heart rate--group I trained at 155 bpm, group II, 140 bpm and group III, 125 bpm.

At the beginning of each week the aerobic capacity of all subjects was determined from a nomogram (3) designed for this purpose. Subjects were re-tested six weeks after the termination of training.

Analysis of these results revealed that over the six week training period significant differences in predicted maximal oxygen uptake occurred between the population means. In terms of net improvement, the means of groups I and II differed significantly from those of the control and group III. No other differences were significant.

For the three training groups, mean work load changes were recorded after the second week of training. The only difference achieving significance was between the means of groups I and III.

Six weeks after the termination of training the mean aerobic capacity increases for the three training groups were partially lost.

The results indicate that a thirty-minute training session, three times per week for six weeks results in a significant training effect on the exercise heart rate only if the intensity of training exceeds a rather high level. Presumably, for this sample a critical level falls somewhere within a pulse rate range of 125-140 bpm.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Training is known to effect several changes in the cardio-vascular system. Although the effect of training on the resting, maximum and recovery pulse is open to dispute, a well established observation is that training results in a lowering of the heart rate for a given work load (9, 17, 24). Stated differently, training necessitates an increased work load to elicit a given heart rate.

M.J. Karvonen *et al.*, (23) published the results of a study involving six male subjects aged 20-23 years. The subjects, previously untrained medical students ran on a treadmill for thirty minutes, four to five times per week for four weeks. The speed of the treadmill was adjusted according to the pulse rate of the subjects so that each subject ran at a predetermined pulse rate. In some subjects, the pulse rate during work dropped necessitating an increase in treadmill speed to maintain the original level. In this situation, the training effect on the working heart rate was demonstrated by an increase in running speed:

> It would appear that in order to improve the exercise tolerance of the heart, the intensity of training has to be above a rather high threshold value. The intensity of training may be expressed also as a percentage of the training pulse from the total range of heart rates from rest to the maximum attainable from running. Sixty per cent of range appears to be the critical limit. Above this level the training is effective, below it, the training is ineffective (24).

De Vries (11) expressed Karvonen's theory as a formula. For a subject with a resting pulse of 70 bpm and a maximum of 200 bpm, the

hypothetical critical training level would be 70 + .60(200-70) = 148 bpm. For Karvonen's six subjects the lowest critical rate was 137 bpm. Unless the intensity of training exceeds the threshold, the heart rate for a given work load will remain constant.

Underlying the Astrand-Ryhming (3) predicted maximal oxygen intake test is the basic assumption that a linear relationship exists between heart rate, work load and oxygen uptake through sub-maximal work and work resulting in heart rates of 195 ± 10 bpm. By applying Karvonen's threshold theory to the linear assumption, it follows that in order to increase an individual's aerobic capacity the intensity of training must exceed a critical limit. Training above the threshold will cause a lowering of the working pulse rate for a given work load (or an increase in the work load required for a given heart rate) and hence, an increase in an individual's predicted aerobic capacity.

Hollmann and Venrath (21) demonstrated that unless the heart rate during training remained above 130 bpm., the increase in aerobic capacity was negligible. Contrary to the European findings, Shephard (35) believes that the threshold suggested by Karvonen may be substantially lower for North American subjects, "possibly because pulse rates greater than 120 bpm. are foreign to the experience of our sedentary subjects" (35).

The Problem: By employing the Astrand-Ryhming nomogram for the calculation of aerobic capacity from sub-maximal work, it is the purpose of this study to investigate the existence of a training threshold by statistically evaluating the effect of varied intensities of training on predicted maximal oxygen uptake.

Justification of the Study: The existence of a training threshold requires substantiation. Much has been written concerning functional adaptation of the cardio-vascular system to training stimuli. However, as to the necessary conditions required to achieve these changes, little is known. Intuitively, it seems feasible to suppose that functional changes bear a positive relationship to the intensity of training -- the greater the intensity the more pronounced the physiological adaptations.

The threshold theory challenges such an assumption. Unless the intensity of training exceeds a critical level, the heart rate for a given sub-maximal work load will remain unchanged. Consequently, considerable time and effort may be spent participating in physical activity without achieving one of the major cardio-vascular effects of training.

Limitations of the Study: The following considerations will limit the inferences drawn from this study:

(i) The validity, reliability and underlying assumptions of The Astrand Ryhming Test for the prediction of maximal oxygen consumption.

(ii) The subjects' living habits and the fact that the ambient temperature and humidity of the laboratory were not controlled.

(iii) Individual differences in maximal pulse rates attainable from stationary cycling were not empirically determined.

Definitions of Terms

Maximal Oxygen Intake, Uptake or Consumption (MVO_2): The maximum amount of oxygen an individual can utilize in strenuous physical activity --

relative to the activity performed.

Aerobic Capacity: The term, "aerobic capacity" or more correctly, "power", is used synonymously with the term, "maximal oxygen consumption."

Kilopond (kp): One kilopond is the force acting on the mass of one kilogram (kg) at the normal acceleration of gravity.

Work Load: Work performed against a fixed resistance and measured in kilopond metres per minute (kpm/min.).

Working or Exercise Heart Rate: The heart rate corresponding to a given work load.

Steady State Heart Rate: The tendency for the heart rate to plateau after approximately four minutes of submaximal work and remain constant within ± 5 bpm -- state of equilibrium between oxygen uptake and energy expenditure.

CHAPTER II

REVIEW OF LITERATURE

In the area of exercise physiology, cardiovascular adaptations to training stimuli have been widely investigated. As to the specific nature of these changes, scientific opinion is sharply divided. In interpreting the results of training studies, two problems emerge. Firstly, heart rate response to exercise varies not only with age but from individual to individual. Secondly, and perhaps more importantly, is the apparent lack of standardization. The very terms resting heart rate, maximum heart rate and recovery heart rate abound in ambiguity often because definitional agreement is lacking. In fact, the absence of standardized operational definition appears as the most formidable barrier in facilitating meaningful comparisons.

A further limitation lies in the observation that the heart rate response to a given work load may be influenced by a variety of factors. These include ambient temperature, relative humidity, time of day, digestive functions, fatigue and the individual's emotional state (33). As a consequence, the reliability of interpretation can also be spuriously affected.

It is not surprising that contradictions frequently occur in the literature. Largely, for this reason the study and its associated review of literature are limited to the effects of training on exercise heart rate. Exercise heart rate presents no problem of definition, it is simply the heart rate corresponding to a given work load.

Exercise Heart Rate: Agreement exists as to the effect of training

on the working or exercise heart rate. Training results in a decrease in heart rate for a given work load, or conversely, an increase in the work required to attain a given heart rate (23, 9, 17). No challenge is offered to the premise that training results in a lowering of the working pulse rate for a given work load. Rather, it is a question of intensity -- must the heart rate exceed a critical level to achieve the physiological changes that are reflected in the lower exercise heart rate of the trained athlete?

Training Threshold: In a study conducted by Karvonen *et al*., (23), six sedentary subjects trained on a treadmill for thirty minutes, four to five times per week for four weeks. The speed of the treadmill was adjusted according to the pulse rate of the subjects so that each subject ran at a predetermined pulse rate. In some subjects, the pulse rate during work dropped necessitating an increase in treadmill speed to maintain the original level. In this situation, the training effect on the working heart rate was demonstrated by an increase in running speed. From the results of the training programme, the authors concluded that cardiovascular adaptations, namely, resting rate, working rate and maximum rate are largely independent. Karvonen (24) maintains that in order to attain all major effects of training it is necessary to train at a rather high heart rate level. For an individual to demonstrate a lower exercise heart rate for a given work load, the intensity of training must exceed a critical limit. This limit was expressed as being, "60 per cent of the available range from rest to the maximum attainable by running -- or above appr. 140 per minute." (23)

Implicit in both predicted and actual measurements of aerobic capacity

is the basic assumption that a linear relationship exists between heart rate, work load and oxygen consumption through sub-maximal work and work resulting in heart rates of 195 ± 10 bpm. By applying the threshold theory to the linear assumption, it follows that in order to increase an individual's maximal oxygen consumption the intensity of training must exceed this critical limit. Although the critical limit suggested by Karvonen <u>et al</u>. is often cited in literature pertaining to the effects of exercise (29, 32, 11, 10), evidence in support of this theory is by no means conclusive.

In a study by Hollmann and Venrath (21), subjects trained on a bicycle ergometer, 30 minutes daily for a period of five weeks. Unless the heart rate during training exceeded 130 bpm. the increase in aerobic power was negligible (2099 to 3067 ml.). However, if the working or exercise heart rate exceeded 130 bpm., the mean MVO_2 increased from 3067 to 3565 ml. in the same period of time. Contrary to the European findings, Shephard (35) believes that the threshold suggested by the Scandanavian researchers may be substantially lower for North American subjects, "possibly because pulse rates greater than 120 bpm. are foreign to the experience of our sedentary subjects (35)."

<u>Astrand-Ryhming Nomogram -- Theoretical Basis</u>: The validity of the Astrand-Ryhming Nomogram (1, 3) as a predictor of maximal oxygen consumption rests on the following assumptions:

1. A linear relationship exists between heart rate, work load and energy expenditure (VO_2) through sub-maximal work and up to work resulting in heart rates as high as 195 bpm. (± 10).

2. The mechanical efficiency of stationary cycling is constant for

both well and poorly conditioned individuals alike, so that differences in performance may be accredited to cardio-respiratory function rather than skill.

3. The stress of work overrides the effect of emotion on the behaviour of the working pulse.

4. Heart rate achieves a steady state after approximately six minutes of sub-maximal work.

Relationship Between Heart Rate, Work Load and Energy Expenditure: The existence of such a relationship has been a widely investigated and controversial aspect of the Astrand test. Astrand and Ryhming (3) indicate that this relationship is only accurate between heart rates of 125-170 bpm.

> Within these limits there is normally an almost linear increase in metabolism (VO_2) with heart rate ..... the slope of the curve is determined by the subjects aerobic capacity. We do not know whether there is a linear relationship between the cardiac output and the oxygen intake, nor the variations of stroke volume and arterio-venous O_2 difference as the stress on the circulation increases with heavier work load. Consequently, the physiological explanation of the findings of a high correlation between the heart rate when performing sub-maximal work and the maximal oxygen intake is far from obvious (3).

Rodahl, et al. (31) are a little less cautious when they state:

> In any given individual there is a linear relationship between O_2 uptake and heart rate during sub-maximal work. The slope of this line changes with the state of physical training or physical fitness; a fit person is able to transport the same amount of oxygen at a lower heart rate than an unfit person. This relationship in general is independent of sex and age, although females require higher heart rates to transport the same amount of oxygen than males (31).

Wyndham, et al., (41) agree that at lower sub-maximal work loads a linear relationship exists between heart rate and oxygen consumption, however, at high work loads, the relationship is no longer linear but

becomes instead, asymptotic. They found O_2 consumption can still increase after the maximal pulse rate has been attained. According to Wyndham, et al. the nomogram depends upon a criterion which is implied rather than explicitly stated, that is, that maximum oxygen intake and maximum pulse are attained at approximately the same rate of work -- a straight line relationship.

Irma Astrand (1) answered the criticism by saying that it is not the premise of the nomogram that heart rate is a rectilinear function of metabolism through the entire range of values. Nevertheless, Rowell, et al. (33) suggest that the nomogram may have been constructed in the following manner:

> If the VO_2 to pulse rate slope is originated at 60 bpm. and zero VO_2 and then extrapolated through a single value for sub-maximal VO_2 and pulse rate to 195 bpm., the VO_2 at the latter point corresponds exactly to that read from the nomogram as predicted maximal VO_2. The pulse rate at 50% of this predicted maximal VO_2 will always be 128 bpm. (33).

Boothby (7), Krogh and Lindhard (26), Schneider (34), Erickson et al. (15), and Dill (13) have all demonstrated an approximate rectilinear relationship between increasing work loads, oxygen consumption and heart rate.

Taylor (38) limited a study to two subjects in which twenty-four individual determinations were conducted on each subject over a period of two months. For these subjects, correlation coefficients of 0.97 and 0.96 were found between work load and heart rate. In fifty per cent of all the cases studied there was no deviation in the linear increase of oxygen intake at exhaustion and in the remaining cases the value accelerated more than fell off. From the results, the investigator concluded that heart rate, total ventilation, oxygen consumption

and respiratory quotient all increase with work load in an approximately linear fashion and the ultimate level reached is subject to individual variation.

However, as Rowell et al. (33) point out, such factors as emotional state, environmental temperature changes, degree of hydration and hydrostatically induced changes from prolonged erect posture can all have a direct influence on the sub-maximal working pulse and as a result, offset the linear relationship between heart rate and oxygen consumption.

Mechanical Efficiency: Astrand (4) defines mechanical efficiency in terms of the total work performed multiplied by 100 and divided by the difference between the total energy used and the basal energy exchange. Mechanical efficiency calculations were performed on twenty-one male and thirty-one female subjects at various work intensities on the bicycle ergometer. It was found that the values differed by less than 0.1% from the means of all the calculations. For the males the efficiency varied between 23.3 and 23.7% while the values for the females ranged between 22.5 and 23.1%. For the subjects used, aged 4-33 years, no significant variation in mechanical efficiency was shown with age.

Astrand (1) found that among male subjects there was a significantly lower mechanical efficiency at 300 and 600 kpm per minute for the oldest group than for the youngest group. In the female subjects this lower efficiency was observed at work loads of 300 and 450 kpm per minute but at 600 kpm per minute there was no difference between the groups of relatively young housewives and physically well-trained students.

In simple movements where large muscle groups are involved, mechanical efficiency fluctuates only slightly. From work on the bicycle

ergometer the standard variation in mechanical efficiency was ± 8% between athletes, normal, healthy men, and cardiac patients. However, the more complicated the work task, the greater are the individual variations in mechanical efficiency.

Rodahl, et al. (30), using two random samples compared the mechanical efficiency of Swedish and American children aged 8-18 years on the bicycle ergometer. They found that within an age range of 8 to 18 years, the mechanical efficiency was 23% for males and 21% for the females. At a work capacity of 600 kpm the mechanical efficiency for 14 year old Stockholm boys was 23.1% compared with 23.9% for Philadelphia boys. Statistically, this difference was not significant.

Taylor, et al. (37) believe that repeated bouts of work can result in a substantial change in mechanical efficiency due to a learning factor. In areas where cycling is common the difference in the oxygen requirement for weight is small between individuals. However, it is not certain if this will be the case in areas where bicycle riding is not so popular.

The Astrand-Ryhming Nomogram assumes that the cardio-respiratory functions attain a "steady-state" after approximately six minutes work. In the first two to three minutes of work there is a rapid increase in pulmonary ventilation, however, the pulse rate and metabolic rate usually reach a plateau between the third and fifth minutes of work (31).

Wyndham, et al., (41) report that for work requiring an oxygen uptake of two litres per minute, the heart rate reached a steady state between five and ten minutes and remained at this level for one-two hours.

Validity and Reliability: Using a sample of twenty-seven male and thirty-one female well trained subjects twenty to thirty years of age,

Astrand and Ryhming (3) determined the validity of their nomogram by comparing the calculated MVO_2 values with those determined in maximal tests. A statistical analysis of these values yielded a mean difference between calculated and determined aerobic capacity of 0.02 ± 0.051 litres of oxygen per minute for males and 0.01 ± 0.051 litres per minute for females. For two-thirds of the cases, the standard deviation was less than 6.7% for males and 9.4% for females. With a lower rate of work, 900 kpm/min. for males and 600 kpm/min. for females, the respective standard deviations were 10.4% and 14.4%. As a further test of validity, Astrand compared the determined MVO_2 values for eighteen well trained male subjects eighteen to nineteen years with predicted MVO_2 values calculated from sub-maximal step and treadmill tests. The mean difference between the predicted and determined MVO_2 was 0.006 ± 0.066 litres per minute in the step test and 0.020 ± 0.058 litres per minute in the treadmill test. In both cases, the standard deviation was less than 7%.

For thirty-one female subjects and twenty-eight male subjects (twenty to thirty years of age), the maximal oxygen intake was calculated from heart rate and oxygen uptake for both a cycle and step test. The two MVO_2 values were compared, and the mean difference between the means was 0.003 ± 0.052 litres per minute for the females and 0.025 ± 0.057 for males. The respective standard deviations were 9.5% and 7.3%.

Subsequent Evaluations of the Nomogram: The validity of the nomogram was first seriously challenged by Wyndham *et al*., (41) in 1959. Logically, if not practically, Wyndham's argument is sound. For Wyndham, it is feasible to claim that a heart rate of 128 bpm is equivalent to 1/2 MVO_2 (males) only if a straight line relationship between pulse rate

and oxygen consumption exists. In fact, the simple procedure of the Astrand-Ryhming Nomogram rests upon this implied criterion.

Wyndham, et al., based their criticism on the data obtained from four highly trained young men. At least five separate determinations were made of oxygen uptake and heart rate at various levels of work on a bicycle ergometer, up to and above the subjects' MVO_2. From the values obtained, the resulting curves were tested for goodness of fit. The researchers observed that a linear relationship between oxygen uptake-heart rate does not exist over the full range of values for heart rate. Only at lower rates of work is there a straight line relationship between oxygen consumption and heart rate. At high work loads, the curves tend toward an asymptote. The oxygen curve reaches its asymptote more slowly than does heart rate. Therefore if heart rate is plotted against oxygen intake and a straight line fitted and extrapolated to the maximum value of heart rate to oxygen intake, the corresponding value is an under-estimate of the actual measured MVO_2. According to the experimenters, the Nomogram under-estimates MVO_2 by 0.32 ± 14 litres per minute.

This criticism was also extended to an established direct test of MVO_2, namely, that of Taylor, Buskirk and Henschel (39). For Taylor, et al., the criterion for MVO_2 is just after the curve begins to part from the linear. According to Wyndham, et al., higher work loads were not studied by Taylor, et al., and this probably accounts for the fact that they too missed the slow approach of oxygen intake to the asymptote.

Irma Astrand (1) answered the Wyndham criticism by claiming that the nomogram does not assume, "that heart rate is a rectilinear function of oxygen uptake throughout the entire range of values" (1). The nomo-

gram was constructed empirically where the predicted values of oxygen uptake were compared with the determined values. Furthermore, the asymptotic curve described by Wyndham, et al., had previously been observed in subjects suffering from slight hypoxia.

In support of Astrand, Rowell, et al., (33) suggested that the discrepancy observed by Wyndham et al., was due, not to the asymptotic approach of oxygen intake and heart rate to maximal values, but simply to the fact that the four subjects in the study averaged a maximal pulse rate of only 178 bpm. Since the nomogram requires extrapolation of pulse rates to 195 bpm. and since the pulse rates indicated by Wyndham, et al., at 50% of MVO_2 were less than 128 bpm., the results should have been to over-estimate the determined MVO_2 value:

> Their estimates are incorrect since Wyndham, et al., were actually assessing the difference between observed MVO_2 and MVO_2 estimated by extrapolation of the VO_2 -- pulse rate slope to observed maximum heart rate which in their study of four well-trained subjects averaged only 178 bpm. . . this procedure does not provide the same value for MVO_2 as that obtained by the nomogram since the latter requires extrapolation to 195 bpm. Contrary to their conclusions, the nomogram should over-estimate true maximum oxygen intake since Wyndham and co-workers show in their graphs pulse rates of 50% MVO_2 which were less than 128 bpm. Using the data from these graphs, predicted values of MVO_2 from the nomogram would be roughly 3.3, 2.8, 3.6 and 3.0 litres/oxygen/minute as opposed to the respective observed values of 3.01, 2.72, 2.13 and 3.01 1./02/min. (33:926).

Hettinger, et al., (22) compared the predicted values of MVO_2 determined from the nomogram to measured intake values as determined by the bicycle ergometer. The experiment involved twenty-eight American policemen twenty to thirty years of age. For this sample, mean predicted MVO_2 was 2.62 litres per minute, which is considerably less than the 4.11 litres per minute cited by Astrand and Ryhming (3) in their

original paper. More importantly, the study claimed a significant difference between the two MVO_2 measures but no figure was presented. Nevertheless, in a study using a sample fitting the description of Hettinger, et al., Rodahl and Issekutz (31) cited a correlation coefficient of 0.47 between the actual and predicted MVO_2 tests.

Studies advocating the value of the nomogram as a predictor of MVO_2 soon swamped the initial scepticism. Borg and Dahlstrom (8) using a bicycle ergometer test studied the effect of two different work levels (600 and 900 kpm) of 6 minutes duration on seventy-eight, twenty year old army recruits. The intra-test consistency was assessed by correlating heart rates after 2, 4 and 6 minute work periods. The highest intra-test correlations were found between the pulse rates from the fourth to the sixth minute at a work load of 900 kpm. per minute. On the first test, this reliability coefficient value was 0.97, and on the re-test, 0.98. The correlation coefficient values for 600 kpm. per minute were 0.90 and 0.94 respectively. The correlations for pulse rates at the second and fourth minute are somewhat lower.

The test re-test correlation coefficients for heart rates averaged between 0.50 and 0.60 for the 600 kpm level and between 0.60 and 0.70 for the 900 kpm level. These low correlations may well be attributed to the fact that the re-test was administered almost a year later.

Larson, et al. (27), using both direct and indirect bicycle MVO_2 tests, obtained work capacity values for 12 boys, half of whom were diabetic. The determined values for MVO_2 averaged 0.2 litres per minute higher than the values calculated from the nomogram. Although the calculated values were 7.9% lower, the difference was not significant. The

experimenters concluded that the Astrand-Ryhming Nomogram was applicable to adolescents, diabetics and non-diabetics in addition to the original twenty to thirty year old group from which the nomogram was constructed.

In 1964, de Vries and Klafs (12) investigated the validity of several sub-maximal work capacity tests by comparing the predicted values with an actual MVO_2 determined on a bicycle ergometer. The subjects from which the values were obtained were sixteen physical education students twenty to twenty-six years of age. Of the sub-maximal tests used, the Sjostrand test, the Harvard Step Test and the Astrand Ryhming test yielded a significant correlation between the predicted and actual values. The Astrand Ryhming Nomogram had a correlation coefficient of 0.736 with a standard error of ± 0.395 l/min. when compared to the maximal test.

Rowell, <u>et al</u>. (33), advocate caution when using heart rates at sub-maximal work, since pulse rates can vary independently of the O_2 uptake. Factors such as emotional state, degree of physical conditioning, ingestion of food, total circulating haemoglobin, hydration, environmental temperature changes and hydrostatically induced changes from prolonged erect posture can all have a direct influence on the sub-maximal working pulse.

These investigators also found that the nomogram under-estimated determined MVO_2 by 5.6% ± 4 in a group of endurance athletes. The magnitude of error varied depending on the individual's state of physical condition. The nomogram under-estimated determined MVO_2 by 26.8 ± 7.2% and 13.7% in a sedentary group before and after 3 months of physical training. These results are in agreement with Astrand and Ryhming's findings with well trained subjects.

Glassford, et al. (18), using twenty-four males aged seventeen to thirty-three obtained MVO_2 values from the Astrand-Ryhming predicted test and three direct tests, namely Mitchell, Sproule and Chapman (treadmill), Taylor, Buskirk and Henschel (treadmill) and the Astrand (bicycle ergometer). In addition, the Johnson, Brouha and Darling physical fitness test was administered. The two treadmill tests and the indirect test yielded significantly higher mean values than did the direct bicycle test. However, no other significant differences in mean values occurred. Correlation coefficients between the various oxygen uptake tests as well as the fitness test were all found to be significant. No correlation obtained proved to be significantly greater than any other. The results indicate that the direct treadmill tests, employing greater muscle mass and possibly less local fatigue, yield higher maximal oxygen uptake values (8%) than does the direct bicycle ergometer test. The values in litres per minute obtained on the Astrand-Ryhming predicted test correlated 0.80 with the Johnson, Brouha and Darling test of physical fitness, 0.78 with the Mitchell, Sproule and Chapman test, 0.72 with the Taylor, Buskirk and Henschel test and 0.65 with the Astrand actual test. With body weight partialled out, the resulting correlations were of the same magnitude. The relationship between the nomogram values and any one set of values determined by the direct technique was as good as the relationship between the values of any two direct measures. The investigators concluded that the nomogram provides a valid estimation of MVO_2 in a population unaccustomed to cycling.

CHAPTER III

METHODS AND PROCEDURES

Subjects: A sample of twenty-four volunteers was recruited from among first year male students attending the University of Alberta. A preliminary Astrand-Ryhming test was administered to all subjects in order to familiarize them with the bicycle ergometer and testing procedure. On the basis of the obtained scores, expressed as a ratio between oxygen uptake (ml/min) and body weight (kg), subjects were ranked from highest to lowest.

From six stratified ranks (n = 4) subjects were assigned by random replacement to four groups (n = 6). This procedure was an attempt to establish four homogeneous groups. Three of the groups were destined to undergo a training programme of a predetermined intensity, while the remaining group served as a control. The rationale behind using a control group was to investigate the possibility of a learning effect as a result of familiarity with the test. Since the test is vitally concerned with heart rate response to exercise, it is possible that learning and/or emotional influences may affect test performance.

At the beginning of each week, all groups underwent the Astrand-Ryhming test. Of the three training groups, each group trained at a different but constant pulse rate for half an hour, three times per week for six weeks. Group I trained at a pulse rate of 155 bpm; group II, 140 bpm. and group III 125 bpm. Groups I and II trained above and group III trained below the hypothesized threshold (23). Six weeks after the termination of the training period all subjects were re-tested.

Subjects were requested to make themselves available for testing and training at the same time on the appropriate day and to refrain from engaging in physical activity over and above that to which they were normally accustomed.

Heart Rate Recordings: Pulse-rates were recorded by means of a Sanborn 500 Viso-Electrocardiograph. After smearing the electrodes with conductive paste, two electrodes were secured on either side of the chest parallel to the fifth inter-costal space. On the back, a reference electrode was secured medially to the right scapula. Heart-rate was calculated from the distance (in millimetres) between three beats as described by the cardiogram.

The Astrand-Ryhming Test for the Prediction of Maximal Oxygen Consumption: The test was performed on a Swedish produced Monark Bicycle Ergometer modified from a design by Von Dobeln (6). The work level can be measured and graded by means of a sinus balance which controls the tension of the brake belt. The deflection of the pendulum is read off on a scale graduated in kiloponds (kp).

The gearing and circumference of the wheel have been so dimensioned that one complete turn of the pedals moves a point on the rim six metres. A calibrated electric metronome was used to establish a pedalling frequency of 50 rpm while the actual revolutions per minute were recorded on an electric revolution counter.

The performed external work for each minute can be accurately calculated from a knowledge of the work load setting and frequency of pedalling. The braking power (kp) multiplied by the distance pedalled per minute (m/min) gives the amount of work in kilopond metres per minute

(kpm/min).

Two minutes before commencement of the test the subjects pre-exercise heart rate was recorded. Each subject then pedalled at a constant work load which would elicit a pulse rate within a range of 125-170 bpm. in six minutes (3). Heart rate recordings were made on a Sanborn 500 Viso-electrocardiograph during the last five seconds of each minute. The subject worked at this level until a steady state was attained i.e., the heart rate between the fifth and sixth minute fluctuated by less than ± 5 bpm. If the pulse rate fluctuation exceeded this criterion, the subject continued to ride until a steady pulse rate was reached.

By the appropriate application of the subject's steady state heart rate and corresponding work level to the nomogram a predicted maximum oxygen consumption value was calculated.

Training Procedure: Each training group trained at a constant pulse rate for half an hour, three times per week for six weeks. Group I trained at a pulse rate of 155 bpm.; group II 140 bpm. and group III, 125 bpm. Groups I and II trained above and group III below the hypothesized threshold (23).

The training schedule was organized so that each subject presented for training at the same time on a given day. Training was conducted in groups of three with a one minute time interval separating each subject.

During the last ten seconds of each five minute period the subject's pulse rate was determined from an electro-cardiograph and the corresponding work load and pedalling frequency recorded. If the pulse rate deviated ± 5 bpm. from the pre-determined rate appropriate adjustments were made to the braking tension.

Calibration of the Bicycle Ergometer: The brake drum was removed and the mark on the pendulum set at "zero". A calibrated metal weight of one kilogram (kg) was added to the end of the lever and the resulting deflection of the pendulum mark read from the scale (kp). A second kilogram weight was added and the process continued up to the end of the scale ("7-kp"). If adjustment was required it was effected by means of an adjusting screw which altered the centre of gravity of the sinus balance.

Statistical Treatment: Since differences in the initial level of performance were observed, means were tested for significance of differences by a technique providing for a two-way analysis of covariance with repeated measures on one factor (40).

Mean net improvement was also tested for significance of differences with a one-way analysis of variance technique (16). Where the analysis yielded a significant over-all F, means were compared two at a time using Duncan's New Multiple Range Test (14).

CHAPTER IV

RESULTS AND DISCUSSION

Results

Group mean, standard deviation and range values for height, weight and age are depicted in Tables I-IV respectively.

TABLE I

DATA FOR HEIGHT, WEIGHT AND AGE
GROUP I (155 bpm.)

Parameter	Mean	Standard Deviation	Range
Height (in.)	69.17	0.85	68-70.5
Weight (kg.)	66.17	7.27	57-78
Age (yrs.)	18.83	0.98	18-20

TABLE II

DATA FOR HEIGHT, WEIGHT AND AGE
GROUP II (140 bpm.)

Parameter	Mean	Standard Deviation	Range
Height (in.)	69.92	2.25	66-72.5
Weight (kg.)	73.33	10.67	61-87
Age (yrs.)	18.33	1.03	17-20

TABLE III

DATA FOR HEIGHT, WEIGHT AND AGE
GROUP III (125 bpm.)

Parameter	Mean	Standard Deviation	Range
Height	69.75	3.00	64-72
Weight	73.00	14.60	51-90
Age	20.33	2.07	18-24

TABLE IV

DATA FOR HEIGHT, WEIGHT AND AGE
CONTROL GROUP

Parameter	Mean	Standard Deviation	Range
Height (in.)	69.42	2.00	67-72.5
Weight (kg.)	74.83	13.28	61-94
Age (yrs.)	19.50	1.87	18-23

Tables V and VI summarize the analyses of variance and co-variance for predicted maximal oxygen consumption expressed in litres per minute and millilitres per minute respectively.

TABLE V

ANALYSIS OF VARIANCE AND COVARIANCE OF PREDICTED MAXIMAL OXYGEN CONSUMPTION FOR THE FOUR GROUPS EXPRESSED IN LITRES PER MINUTE

Source of Variation	Sum of Squares	df	Mean Square	F
A (Between Groups)	7.1	3	2.4	.7
Subj. W.A.	67.7	20	3.4	
B (Between Periods)	3.1	5	.6	10.0*
AB (Interaction)	1.7	15	.1	
Residual	6.2	100	.06	
A (adj.) Between gps.	3.7	3	1.2	5.5*
Subj. W.A. (adj.)	3.8	19	0.2	

* Statistically significant at the .01 level.

TABLE VI

ANALYSIS OF VARIANCE AND COVARIANCE OF PREDICTED MAXIMAL OXYGEN CONSUMPTION FOR THE FOUR GROUPS EXPRESSED IN MILLILITRES PER KILOGRAM OF BODY WEIGHT PER MINUTE

Source of Variation	Sum of Squares	df	Mean Square	F
A (Between Groups)	1,297.5	3	432.5	.89
Subj. W.A.	9,680.8	20	484.04	
B (Between Periods)	613.8	5	122.76	10.42*
AB (Interaction)	401.7	15	26.78	
Residual	1,178.2	100	11.78	
A (adj.) Between gps.	793.97	3	264.66	5.68*
Subj. W.A. (adj.)	884.84	19	46.57	

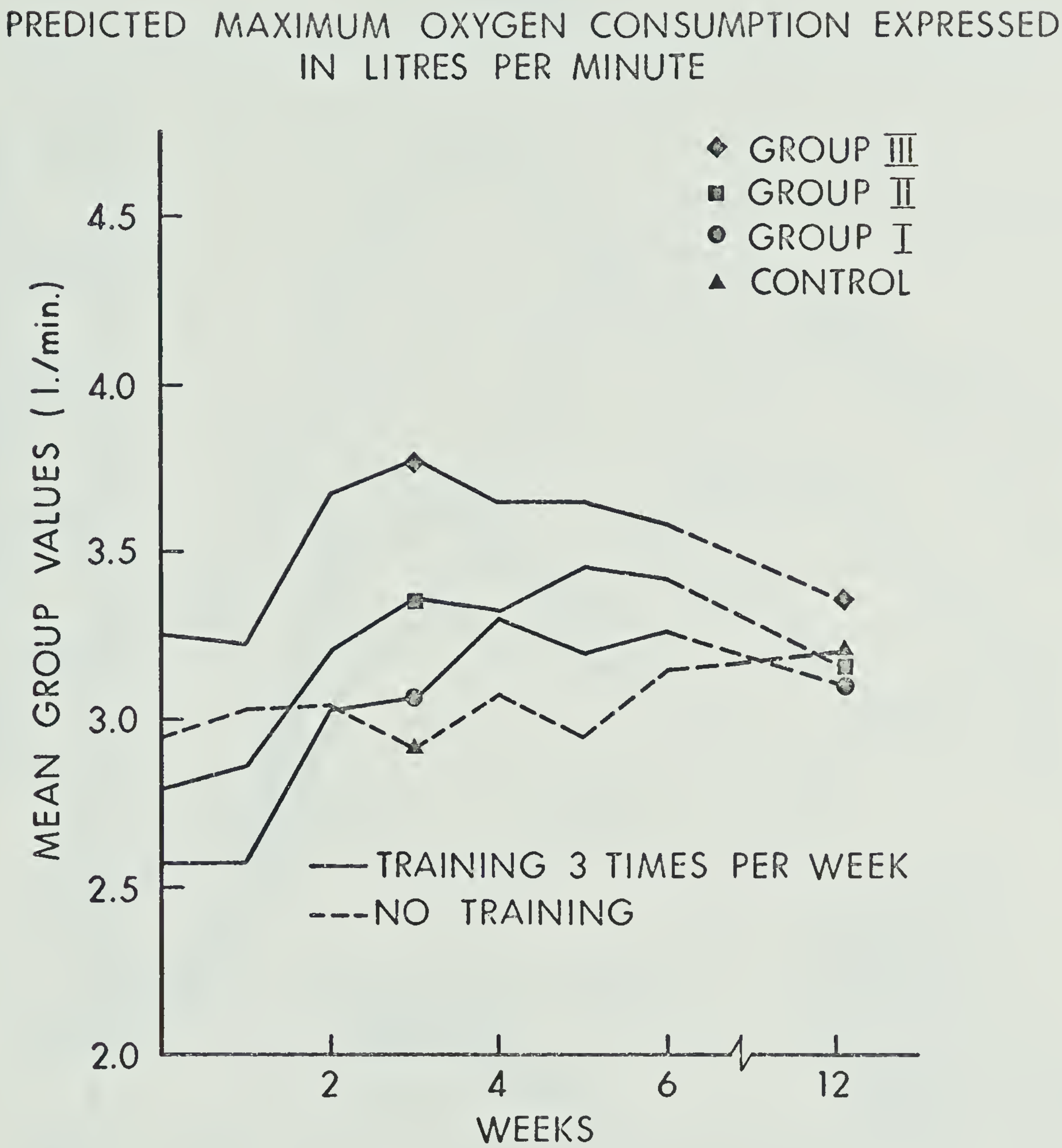
* Statistically significant at the .01 level.

Both analyses of variance yielded significant period or time effects at the .01 level, whereas, significant differences between groups were not demonstrated. However, the analyses of covariance which serve to minimize or adjust for differences in the initial performance levels yielded significant differences between groups (both in l/min. and ml/kg/min.).

Figures I and II graphically depict mean group values for predicted maximal oxygen consumption in litres per minute and millilitres per kilogram of body weight respectively. The two graphs illustrate the differences in performance levels existing prior to the commencement of training. The dotted lines depict aerobic capacity values obtained in the absence of training. Figure II also shows the mean maximal oxygen consumption values for Group III with the exceptional subject excluded.

Changes in work load setting for the three training groups were also analysed using the analysis of covariance technique. The analysis is summarized in Table VII.

Period differences are shown to be significant at the .01 level of confidence. Although the modified or adjusted F ratio for between groups approaches significance at the .01 level, the differences are only significant at the 5% level of confidence. The changes are graphically illustrated in Figure III.



PREDICTED MAXIMUM OXYGEN CONSUMPTION EXPRESSED IN LITRES PER MINUTE
GROUP III
GROUP II
GROUP I
CONTROL
MEAN GROUP VALUES (l./min.)
4.5
4.0
3.5
3.0
2.5
2.0
TRAINING 3 TIMES PER WEEK
NO TRAINING
2
4
6
12
WEEKS

FIGURE I

PREDICTED MAXIMUM OXYGEN CONSUMPTION EXPRESSED IN MILLILITRES PER KILOGRAM OF BODY WEIGHT PER MINUTE

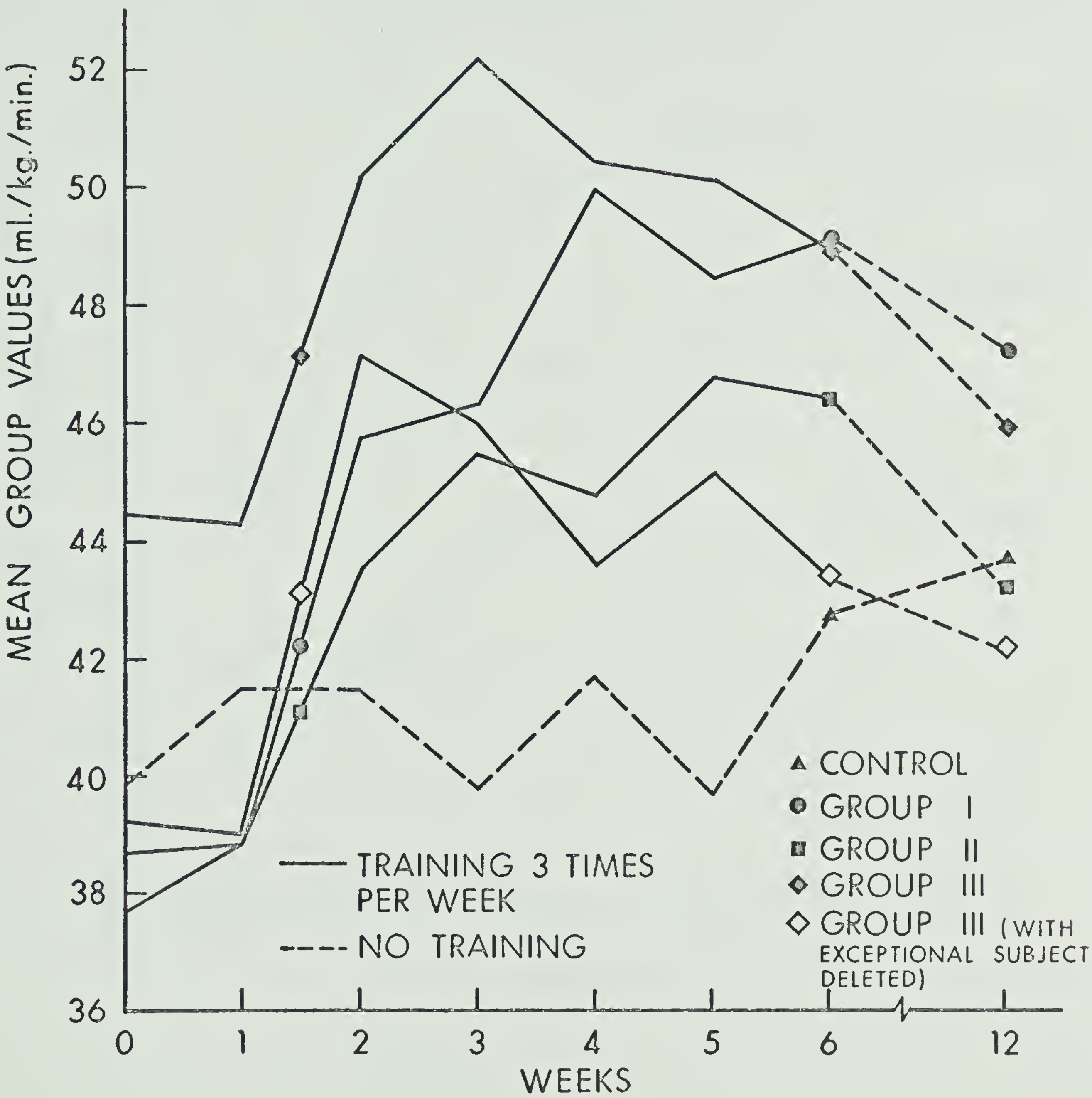


FIGURE II

GROUP TRAINING WORKLOADS-RESISTANCE EXPRESSED IN KILOPONDS

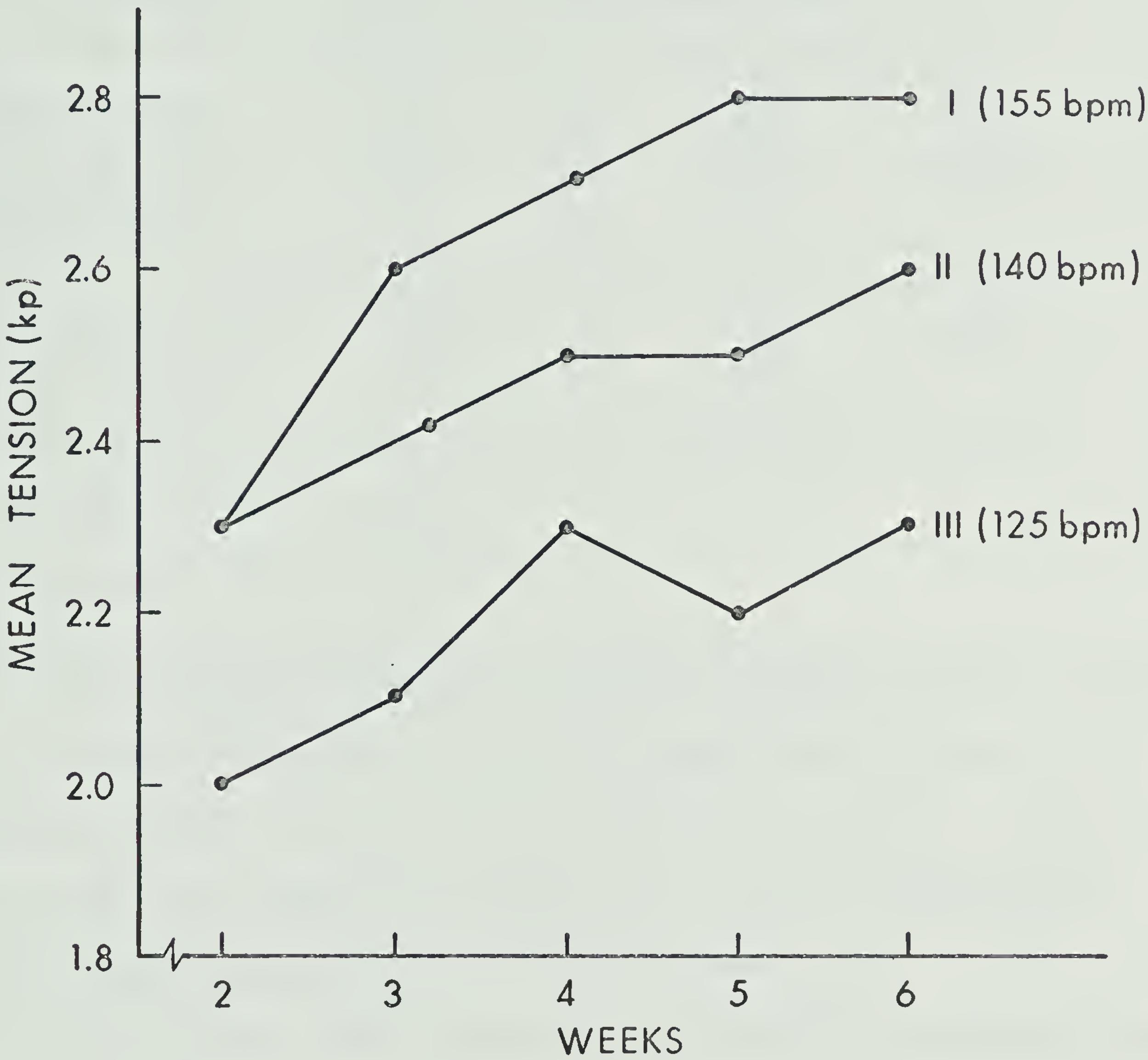


FIGURE III

TABLE VII

ANALYSIS OF VARIANCE AND COVARIANCE OF WORK LOAD SETTINGS (kp) FOR THE THREE TRAINING GROUPS

Source of Variation	Sum of Squares	df	Mean Square	F
A (Between Groups)	3.1	3	1.03	1.23
Subj. W.A.	16.7	20	0.84	
B (Between Periods)	0.4	3	0.13	6.50**
AB (Interaction)	0	9	0	
Residual	.9	60	.02	
A (adj.) Between gps.	1.08	3	.36	4.50*
Subj. W.A. (adj.)	1.50	19	.08	

** Significant at the .01 level.

* Significant at the .05 level.

A simple one-way analysis of variance was used to analyse aerobic capacity changes before and after the six week training period. The analyses expressed in litres per minute and millilitres per kilogram of body weight are summarized in Tables VIII and IX. Both analyses yielded a significant over-all F at the .01 level.

To determine where this significance lay, means were compared using Duncan's New Multiple-Range test. In both analyses (expressed in l/min. and ml/kg/min.) the means of groups I and II differed significantly from the control and group III. No significant differences occurred between any other means. The results of these analyses are given in Tables X and XI.

TABLE VIII

ANALYSIS OF VARIANCE OF DIFFERENCES BETWEEN INITIAL AND FINAL PREDICTED MAXIMAL OXYGEN CONSUMPTION SCORES FOR THE FOUR GROUPS EXPRESSED IN LITRES PER MINUTE

Source of Variation	Sum of Squares	df	Mean Square	F
Between Groups	99.46	3	33.15	13.21*
Within Groups	50.16	20	2.51	
Total	149.62	23		

* Significant at the .01 level.

TABLE IX

ANALYSIS OF VARIANCE OF DIFFERENCES BETWEEN INITIAL AND FINAL PREDICTED MAXIMAL OXYGEN CONSUMPTION SCORES FOR THE FOUR GROUPS EXPRESSED IN MILLILITRES PER KILOGRAM OF BODY WEIGHT

Source of Variation	Sum of Squares	df	Mean Square	F
Between Groups	225.13	3	75.04	14.19*
Within Groups	105.83	20	5.29	
Total	330.96	23		

* Significant at the .01 level.

TABLE X

DUNCAN"S NEW MULTIPLE-RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 4 MEANS EXPRESSED IN LITRES PER MINUTE

Means	.300	.433	.717	.800	Least Significant R
.300	-	.133	.417*	.500*	R = .279
.433		-	.284*	.367*	R = .270
.717			-	.083	R = .260

* Statistically significant at the .01 level.

TABLE XI

DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 4 MEANS EXPRESSED IN MILLILITRES PER KILOGRAM OF BODY WEIGHT PER MINUTE

Means	4.00	5.50	9.83	11.50	Least Significant R
4.00	-	1.50	5.83*	7.50*	R = 4.05
5.50		-	4.33*	6.00*	R = 3.94
9.83			-	1.67	R = 3.78

* Statistically significant at the .01 level.

Figures IV and V graphically illustrate differences in aerobic capacity before and after training. These differences are expressed in litres per minute and millilitres per kilogram of body weight per minute. The corresponding percentage increases are also shown.

PREDICTED MAXIMUM OXYGEN CONSUMPTION - MEAN INCREASE

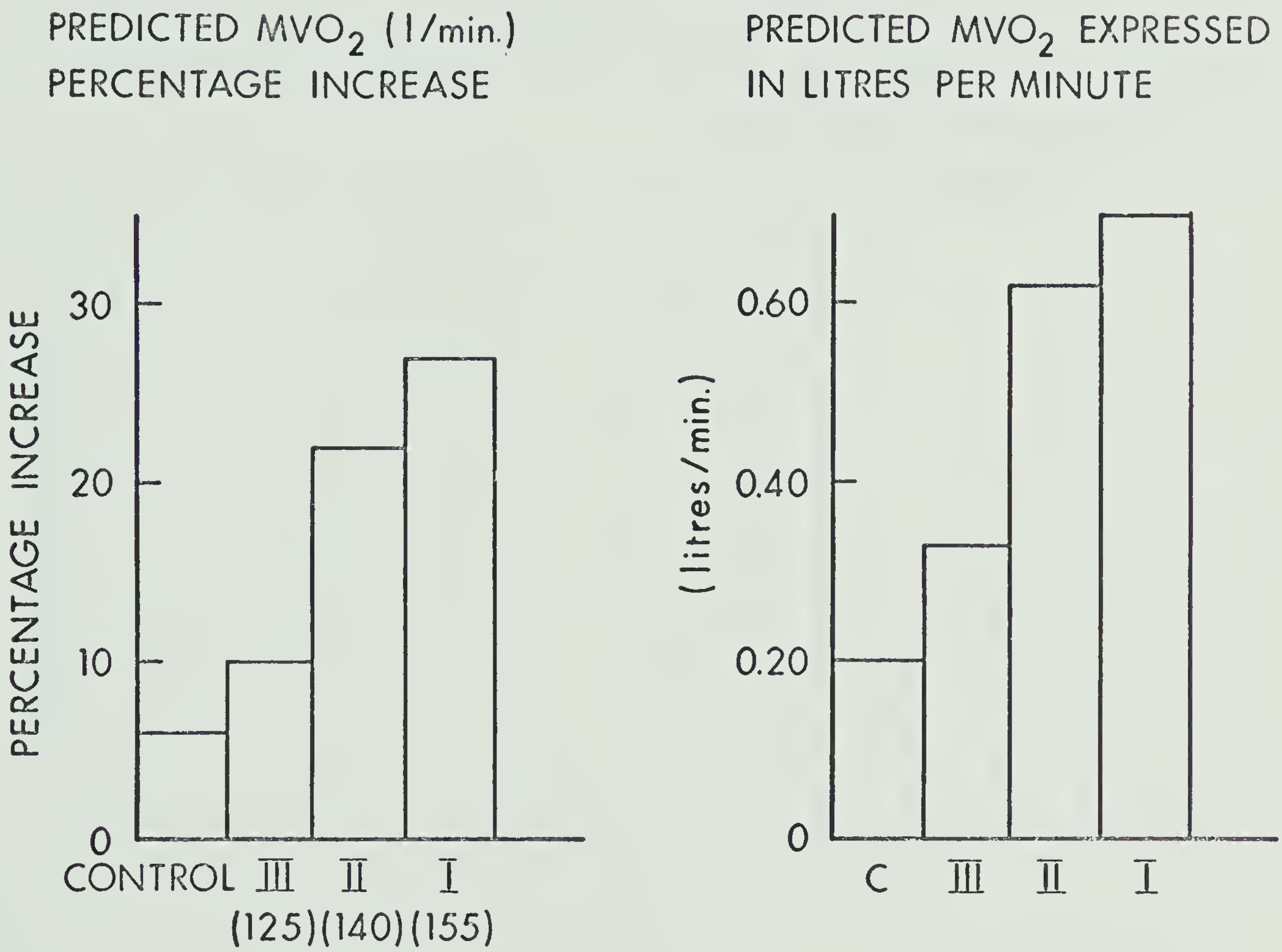


FIGURE IV

PREDICTED MAXIMUM OXYGEN CONSUMPTION - MEAN INCREASE
(ml./kg./min.)

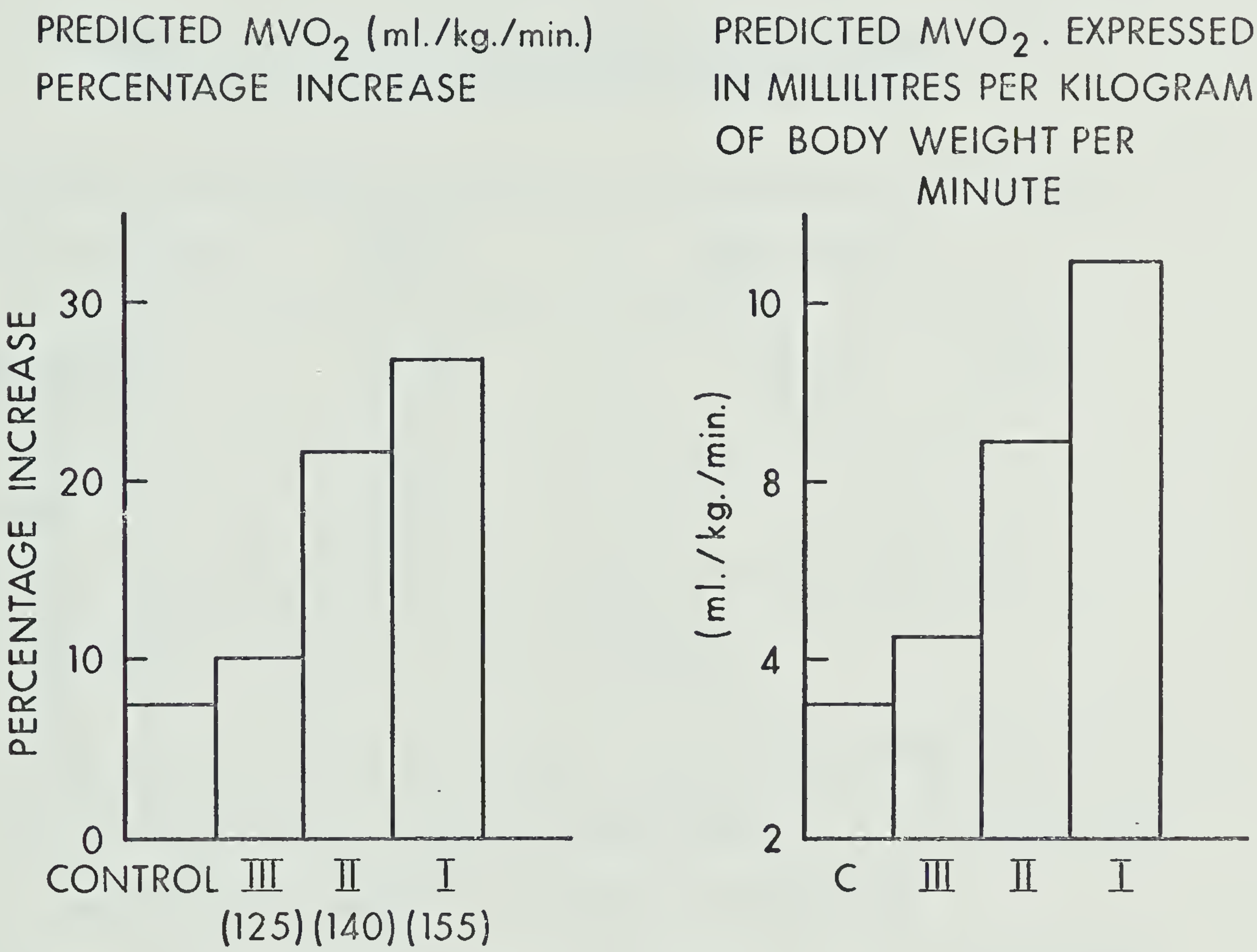


FIGURE V

For the three training groups, differences in work load setting between the second and sixth week of training were tested for significance using a one way analysis of variance. A summary of this analysis is depicted in Table XII. As in the corresponding analysis of covariance, the obtained F ratio is significant at the .05 level of confidence.

TABLE XII

ANALYSIS OF VARIANCE OF CHANGES IN WORK LOAD SETTINGS (kp) FOR THE THREE TRAINING GROUPS

Source of Variation	Sum of Squares	df	Mean Square	F
Between Groups	34.34	2	17.17	4.99*
Within Groups	51.66	15	3.44	
Total	86.00			

* Statistically significant at the .05 level.

A comparison of means by Duncan's New Multiple Range Test revealed that the only difference achieving significance (P = .01) was between groups I and III. The analysis is given in Table XIII.

Figure VI shows graphically net increases in work load setting expressed both in kilopondss and as a percentage.

WORK LOAD (kp SETTING): MEAN INCREASE FOR THE THREE TRAINING GROUPS

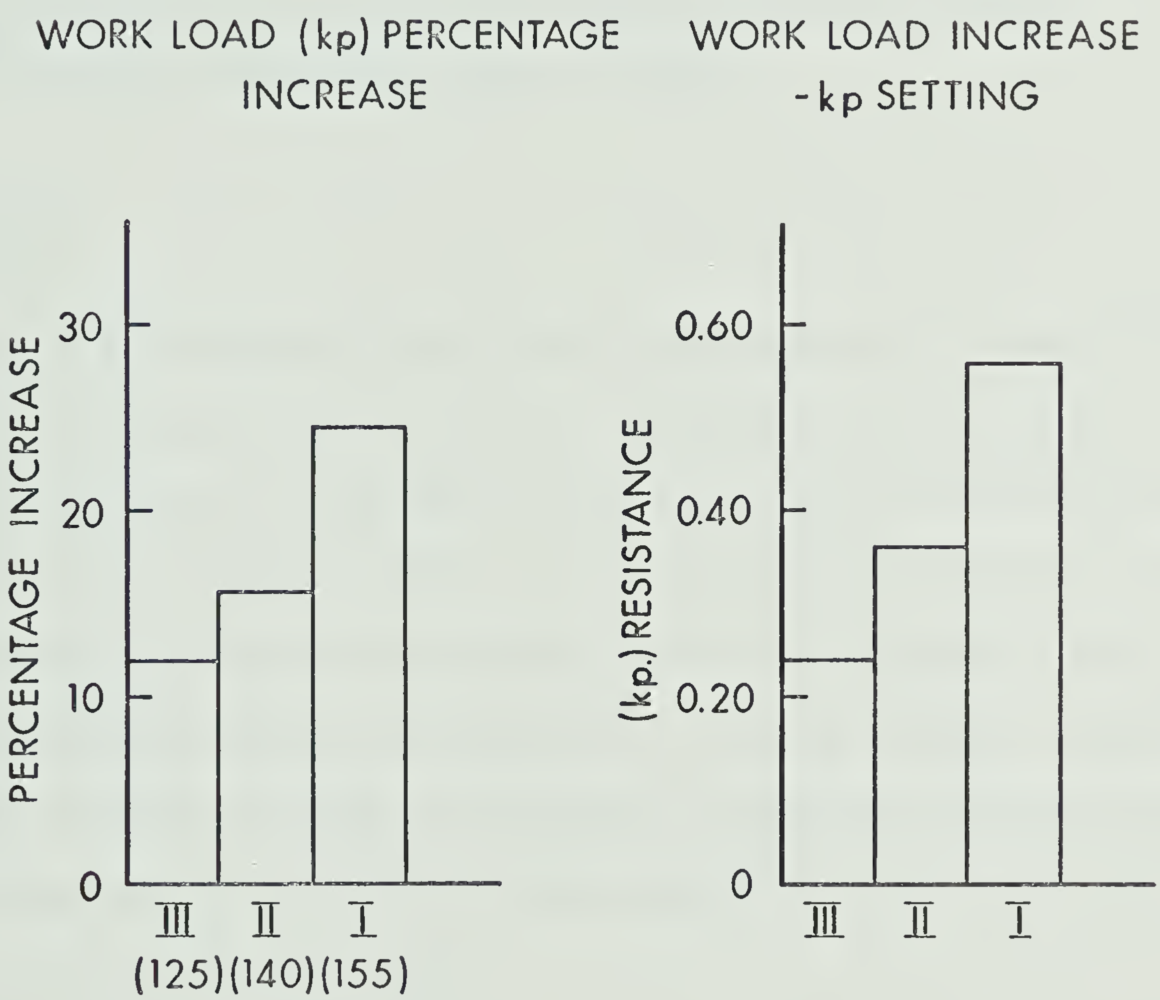


FIGURE VI

TABLE XIII

DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 3 MEANS EXPRESSED IN WORK LOAD (kp) SETTING

Means	.250	.367	.583	Least Significant R
.250	-	.117	.363*	R = .329
.367		-	.216	R = .315

* Statistically significant at the .01 level.

Discussion

One of the assumptions underlying the analyses of variance and covariance is homogeneity of variance. Although moderate departures from this assumption do not seriously affect the sampling distribution of the resulting F statistic (16), the initial population variances of maximum oxygen consumption (expressed in l/m and ml/kg/min.) were tested by a technique devised by Hartley (40). Since the analyses revealed that the differences between the largest and smallest variances were not significant at the .01 level, it was concluded that the variances for all four populations were equal.

Of the twenty-four subjects tested, complete data were obtained for twenty-three. Owing to a virus infection, the fifth subject of group II was unavailable for the Astrand-Ryhming test scheduled after the sixth week of training. Although available three days later, it was felt that an estimated score (19) would provide a more valid prediction of the subject's aerobic capacity since the effects of illness

can adversely affect test performance.

Maximal pulse rates attainable from stationary cycling were not empirically determined and, perhaps, even more fundamental than the assumptions underlying the Astrand-Ryhming test was the assumption that subjects in this study could attain pulse rates from high work levels approaching 195 ± 10 bpm. Astrand points out that an inherent problem associated with a sub-maximal work test is that individual differences in maximal heart rates can give spurious results. The fifth subject of group III (described as the exceptional subject in Figure II) is cited as an example. Not only did he register the highest initial aerobic capacity score (expressed in ml/kg/min.), but, training at a pulse rate of 125 bpm. exhibited what appeared to be a significant training effect. At the completion of testing, the subject rode for seven minutes at a work load setting of six kiloponds. The heart rate recorded in the last ten seconds of exercise was 176 bpm. Compared to his group counterparts, it is quite possible that for this subject an exercise heart rate of 125 bpm. represents a greater proportion of his aerobic capacity.

The mean predicted maximum oxygen consumption values obtained in this study are appreciably lower than those reported by Astrand and Ryhming (3), however, they agree in character with those cited in the North American Literature (18, 22).

Changes in aerobic power are illustrated graphically in Figures I and II and as expected, the analyses summarized in Tables V and VI yielded significant differences between both groups and periods. Because of marked differences in the initial performance levels, these changes appear more obvious when expressed in terms of net improvement.

Although aerobic capacity changes before and after the six week training period are all shown to be positive, it is doubtful whether the responses of the control and group III represent a genuine expression of aerobic improvement. In fact, a study conducted by Macnab and Conger (28) supports this contention. Within an eight day interval, the predicted maximum oxygen consumption of eighty female subjects was calculated on three separate occasions. The experimenters observed a mean aerobic increase with each administration of the test and attributed this improvement to a lowering of the pre-exercise heart rate.

Of particular interest in the present study is the observation that the means of groups I and II differed significantly from those of the control and group III and that no other differences were shown to be significant.

In essence, the analyses summarized in Tables X and XI agree with studies conducted by Karvonen et al. (23), and Hollman and Venrath (21). Under the specific conditions of this study a significant training effect on the exercise heart rate was demonstrated only when the intensity of training exceeded a rather high level, in this case, 140 bpm.

By means of the nomogram, training work load settings were initially determined from a knowledge of the subjects' predicted aerobic capacity. Training began on the premise that pulse rates for the predetermined training loads would plateau after approximately five or six minutes work and remain constant until completion of the thirty minute session. Contrary to evidence cited in the literature (31, 41), the majority of subjects (particularly group I) failed to achieve a steady state. As a consequence, adjustments made to the work load settings were recorded only

after the second week of training. Despite these limitations, the analyses reveal a mean increase in kilopond setting for all groups and a significant difference (P = .01) between groups I and III. The positive changes in mean work levels were achieved largely by the subjects' increasing ability to maintain a constant heart rate throughout the thirty minute training session.

Predicted maximal oxygen consumption values were calculated for all groups exactly six weeks after the termination of the training programme. For the three training groups, the increase in aerobic capacity was partially lost, whereas, the mean value for the control increased.

The relationship between pre-exercise pulse rate and predicted maximal oxygen uptake was not analysed statistically. However, it appears that for moderate work levels differences in individual heart rates before exercise can noticeably modify test performance, particularly, if these differences are in the vicinity of 10-20 bpm. Such differences may explain in part the fluctuations in mean aerobic power exhibited by the control group.

CHAPTER V

SUMMARY AND CONCLUSIONS

Employing the Astrand-Ryhming nomogram for the prediction of aerobic capacity from sub-maximal work loads, it was the purpose of this study to determine the effects of varied intensities of training on the behaviour of the working or exercise pulse rate.

A sample of twenty-four sedentary male volunteers participated in the study. On the basis of initial predicted aerobic capacity scores subjects were ranked in ascending order and from six stratified intervals, randomly assigned to one of four groups. Three of the groups underwent a six-week training programme consisting of a thirty minute bicycle ergometer ride three times per week. The remaining group acted as a control. The subjects in each training group trained at a work intensity corresponding to a predetermined heart rate -- group I trained at 155 bpm., group II, 140 bpm. and group III, 125 bpm. Changes in work load setting required to elicit a given training pulse rate were recorded after the second week of training. At the beginning of each week the aerobic capacity of all subjects was determined from a nomogram designed for this purpose. Subjects were retested six weeks after the termination of training.

For the data collected over the six-week training period, differences between means were tested by a technique providing for a two way analysis of covariance with repeated measures on one factor. Mean net improvement was also tested for significance of differences using a simple one way analysis of variance. Where the analysis yielded a significant over-all F, means were analysed by Duncan's New Multiple Range

Test to determine where the significance lay.

Within the limitations of this study the following conclusions appear to be justified.

1. Over the six-week training period, the analyses revealed significant differences in predicted maximal oxygen consumption, expressed both in litres per minute and millilitres per kilogram of body weight.

2. In terms of net aerobic improvement, the means of groups I and II differed significantly from those of the control and group III. No other differences were shown to be significant.

3. For the three training groups, mean work load changes recorded after the second week of training were all shown to be positive. However, the only difference achieving significance was between the means of groups I and III.

4. Six weeks after the termination of training, the mean aerobic capacity increases for the three training groups were partially lost.

The results indicate that a thirty-minute training session, three times per week for six weeks results in a significant training effect on the exercise heart rate only if the intensity of training exceeds a rather high level. Presumably, for this sample, a critical level falls somewhere within a pulse rate range of 125-140 bpm.

REFERENCES

1. Astrand, I., "Aerobic Work Capacity in Men and Women with Special Reference to Age," Acta Physiologica Scandinavica, Vol. 44, Suppl. 169, 1960.

2. Astrand, I., Astrand, P.O., Christensen, E., Hedman, R., "Intermittent Muscular Work," Acta Physiologica Scandinavica, 48: 448-53, 1960.

3. Astrand, P.O., Ryhming, I., "A Nomogram for the Calculation of Aerobic Capacity from Pulse Rate During Submaximal Work," Journal of Applied Physiology, Vol. 7, pp. 218-221, 1954.

4. Astrand, P.O., Experimental Studies of Physical Working Capacity in Relation to Sex and Age, Copenhagen: Ejnar Munksgaard, 1952.

5. Astrand, P.O., "Human Physical Fitness with Special Reference to Age and Sex," Physiological Reviews, 36:307-29, 1956.

6. Astrand, P.O., Work Tests with the Bicycle Ergometer, Varberg-Sweden, 1967.

7. Boothby, W.M., "Variability of Basal Metabolism," American Journal of Physiology, Vol. 37, pp. 383-417, 1951.

8. Borg, G., Dahlstrom, H., "The Reliability and Validity of a Physical Work Test," Acta Physiologica Scandinavica, Vol. 155, pp. 353-361, 1962.

9. Bliven, F.E., Culpepper, B.W., Rivers, J.L., Goodwin, H.N., "Physical Working Capacity: A Stress Test of Disability," Surgery Forum, 15:454-55, 1963.

10. Costill, D.L., "What Research Tells the Coach About Distance Running," A.A.H.P.E.R. Publication, Washington, D.C., 1968.

11. de Vries, H.A., Physiology of Exercise for Physical Education and Athletics, William C. Brown Co., Iowa, 1966.

12. de Vries, H.A., Klafs, C.E., "Prediction of Maximal Oxygen Intake from Submaximal Tests," Physiol. Ex. Research Lab., California, 1964.

13. Dill, D.B., "Effects of Physical Strain and High Altitudes on the Heart and Circulation," American Heart Journal, Vol. 23, pp. 441-454, 1942.

14. Edwards, A.L., Experimental Design in Psychological Research, Holt, Rinehart, Winston Inc., New York, 1968.

15. Erickson, L., Simonson, E., Taylor, H.L., Alexander, H., Keys, A., "The Energy Cost of Horizontal and Grade Walking on the Motor-Driven Treadmill," American Journal of Physiology, Vol. 145, p. 398, 1946.

16. Ferguson, G.A., Statistical Analysis in Psychology and Education, McGraw-Hill Book Co., Inc., New York, 1966.

17. Frick, M.H., Kontinnen, A., Sarajas, H.S., "Effects of Physical Training on Circulation at Rest and During Exercise," American Journal of Cardiology, 12:142-7, 1963.

18. Glassford, R.G., Baycroft, G., Sedgwick, A., Macnab, R.B.J., "Comparison of Maximal Oxygen Uptake Values Determined by Predicted and Actual Methods," Journal of Applied Physiology, Vol. 20, pp. 509-513, 1965.

19. Goulden, C.H., Methods of Statistical Analysis, John Wiley and Sons Inc., New York, 1956.

20. Guilford, J.P., Fundamental Statistics in Psychology and Education, McGraw-Hill, 1965.

21. Hollmann, W., Venrath, H., as cited in: "Optimum Patterns of Exercise for Healthy Adults," Canadian Medical Association Journal, 96:895, 1967.

22. Hettinger, T., Birkhead, N.C., Howath, S.M., Issekutz, B., Rodahl, K., "Assessment of Physical Work Capacity," Journal of Applied Physiology, Vol. 16, pp. 153-56, 1961.

23. Karvonen, M.J., Kentala, E., Mustala, O., "The Effects of Training on Heart Rate," Annales Medicinae Experimentalis et Biologie Fenniae, Helsinki, 35:307-14, 1957.

24. Karvonen, M.J., "Effects of Vigorous Exercise on the Heart," in Work and the Heart, Ed. Rosenbaum, F.F., and Belknap, E.L., Paul, B., Hoeber, Inc., New York, 1959, pp. 199-210.

25. Karvonen, M.J., "Problems of Training the Cardiovascular System," Ergonomics, 2:207-12, 1959.

26. Krogh, A., Lindhard, J., "A Comparison Between Voluntary and Electrically Induced Muscular Work in Man," Journal of Physiology, Vol. 51, pp. 182-201.

27. Larsson, Y., Persson, B., Sterky, G., Thoren, C., "Functional Adaptation to Rigorous Training and Exercise in Diabetic and Non-Diabetic Adolescents," Journal of Applied Physiology, Vol. 19, pp. 629-635, 1964.

28. Macnab, R.B.J., Conger, P.R., "Observations on the Use of the Astrand-Ryhming Nomogram in University Women," Unpublished Study, University of Alberta, 1966.

29. Munrow, A.D., Pure and Applied Gymnastics, Richard Clay and Co., Ltd., Great Britain, 1963.

30. Rodahl, K., Astrand, P.O., Birkhead, N., Hettinger, T.; Issekutz, B., Jones, M., Weaver, R., "Physical Work Capacity," American Medical Association Archives Environmental Health, Vol. 2 (1961), pp. 499-510.

31. Rodahl, K., Issekutz, B., Muscle as a Tissue, Rodahl and Horvath, Ed., Toronto: McGraw Hill Book Co., 1962.

32. Roskamm, H., "Optimum Patterns of Exercise for Healthy Adults," Canadian Medical Association Journal, 96:895-98, 1967.

33. Rowell, L.B., Taylor, H.L., Wang, Y., "Limitations to the Prediction of Maximal Oxygen Intake," Journal of Applied Physiology, Vol. 19, pp. 919-927, 1964.

34. Schneider, E.C., "A Study of Responses to Work on the Bicycle Ergometer," American Journal of Physiology, Vol. 97, pp. 353-64, 1931.

35. Shephard, R.J., "Physical Activity and Cardio-Vascular Health: Commentary, Canadian Medical Association Journal, 96:899, 1967.

36. Shephard, R.J., Glossary of Specialized Terms and Units," Canadian Medical Association Journal, 96:912-14, 1967.

37. Taylor, H.L., Wang, Y., Bowell, L., Blomquist, G., "The Standardization and Interpretation of Submaximal and Maximal Tests of Working Capacity," Pediatrics, Vol. 32, Suppl., pp. 703-722, 1963.

38. Taylor, C., "The Effect of Work Load on Heart Rate Studies in Exercise Physiology," American Journal of Physiology, Vol. 135, pp. 27-42, 1941.

39. Taylor, H.L., Buskirk, E., Henschel, A., "Maximal Oxygen Uptake as an Objective Measure of Cardio-Respiratory Performance," Journal of Applied Physiology, Vol. 8, pp. 73, 1955.

40. Winer, B.J., Statistical Principles in Experimental Design, McGraw-Hill, New York, 1962.

41. Wyndham, C.H., Strydom, N.B., Martiz, J.S., Morrison, J.F., Peter, J., Potgeiter, Z.U., "Maximum Oxygen Intake and Maximum Heart Rate During Strenuous Work," Journal of Applied Physiology, Vol. 14, pp. 927-936, 1959.

APPENDIX

RAW DATA

AGE, HEIGHT AND WEIGHT OF SUBJECTS

Groups	Age	Height (in)	Begin Weight (kg)	End Weight (kg)
	23	72.5	94	94
	18	70.0	61	61
Control	18	67.0	68	68
	19	69.5	73	73
	19	67.0	65	65
	20	70.5	88	88
	18	68.0	66	66
	20	70.5	78	77
I	20	69.0	65	66
	18	69.0	61	60
	18	70.5	70	71
	19	68.0	57	57
	19	70.0	85	85
	17	71.0	87	88
II	18	66.0	61	61
	18	72.5	66	67
	18	69.0	74	73
	20	71.0	67	67
	20	64.0	51	51
	24	72.0	90	91
III	18	70.0	67	67
	21	69.5	80	81
	19	71.0	65	64
	20	72.0	85	85

INDIVIDUAL RESPONSES TO THE ASTRAND-RYHMING TEST

CONTROL GROUP

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Revolutions	Last Minute $\overline{X}$ Heart Rate
SUBJECT 1											
2.5	80	117	120	129	129	132	132			50	132
2.5	85	123	123	127	132	136	136			50	136
2.5	74	115	122	127	129	132	134			50	133
3.0	102	132	141	145	155	155	155			50	155
3.0	79	122	132	132	138	141	141			50	141
3.0	89	127	136	143	141	148	150			50	149
3.0	110	136	143	150	150	153	155			50	154
SUBJECT 2											
2.0	90	138	138	145	150	155	155			50	155
2.0	79	136	136	138	143	145	148			50	146.5
2.0	87mm	125	132	132	129	130	130			50	130
2.0	74	125	136	138	143	145	150			51	147.5
2.0	73	127	134	143	150	145	145			50	145
2.0	88	132	141	145	145	145	153	153		50	153
2.0	61	122	127	136	138	136	138			50	137
2.0	70	117	123	130	132	134	132			50	133
SUBJECT 3											
2.0	87	122	127	134	138	141	138			50	139.5
2.0	66	110	123	130	125	130	132			50	131
2.0	100	143	150	145	150	153	150			50	151.5
2.0	89	132	136	138	148	141	141			50	141
2.0	74	125	127	134	141	138	141			50	139.5
2.0	66	127	130	130	130	132	136			50	134
2.0	75	125	138	132	125	138	141			50	139.5
2.0	88	129	127	127	127	136	136			50	136
SUBJECT 4											
2.0	64	108	108	117	117	122	122			50	122
2.0	73	118	125	129	132	134	134			51	134
3.0	64	141	148	161	158	161	161			50	161
3.0	71	134	153	148	155	155	158			50	156.5
3.0	99mm	114	125	134	141	145	145			50	145
3.0	61	127	141	150	141	161	161			50	161
3.0	57	127	134	141	136	145	145			50	145
3.0	55	115	125	129	130	136	136			50	136
SUBJECT 5											
2.0	83mm	115	117	120	113	122	122			52	122
3.0	102mm	122	125	130	130	132	138	141		55	139.5
3.0	94mm	129	130	134	130	134	134			50	134
3.0	87mm	123	132	141	138	136	136			50	136
3.0	90mm	127	134	141	138	141	145			53	143
3.0	91mm	125	138	134	132	143	138	141		50	139.5
3.0	87mm	129	136	134	136	138	138			50	138
3.0	58	123	136	132	130	141	141			50	141

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Last Minute Revolutions	$\bar{X}$ Heart Rate
SUBJECT 6											
2.0	70	115	125	125	125	122	127			51	124.5
2.0	69	114	117	117	117	120	120			50	120
3.0	78	132	136	143	145	143	145			50	144
3.0	78	130	138	136	141	141	153	148	150	51	149
3.0	68	115	134	136	141	145	153	150		52	151.5
3.0	65	125	134	136	141	141	145			50	143
3.0	71	127	138	143	145	145	141			50	143
3.0	74	120	132	134	136	138	138			50	138

INDIVIDUAL RESPONSES TO THE ASTRAND-RYHMING TEST

GROUP I

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Revolutions	Last Minute $\bar{X}$ Heart Rate
SUBJECT 1											
3.0	72	132	143	148	155	158	158			50	158
3.0	93	148	158	161	161	173	173			50	173
3.0	74	123	125	134	141	148	148			50	148
3.0	76	125	125	132	138	143	145			50	144
3.0	66	114	125	129	130	134	138			50	136
3.0	72	125	129	138	136	143	143			50	143
3.0	74	127	132	138	136	141	143			50	142
3.0	71	125	129	136	136	145	145			50	145
SUBJECT 2											
2.0	81	103	108	118	120	125	122			46	123.5
3.0	102	138	148	150	161	164	161			52	162.5
3.0	78	138	145	148	150	155	155			50	155
3.0	76	123	125	129	134	138	145	141		50	143
3.0	102	132	138	134	143	145	145			50	145
3.0	91	129	136	136	136	143	145			50	144
3.0	96	123	129	129	136	141	141			50	141
3.0	94	117	125	132	136	143	145			50	144
SUBJECT 3											
3.0	108	150	161	167	170	173	173			51	173
3.0	92	138	148	153	161	161	161			50	161
3.0	88	136	148	153	155	158	158			50	158
3.0	84	134	143	150	155	155	158			50	156.5
3.0	80	127	134	141	143	148	150			50	149
3.0	94	136	138	143	148	145	148			50	146.5
3.0	88	134	136	145	148	145	145			50	145
3.0	94	136	145	153	155	155	155			50	155
SUBJECT 4											
2.5	92	138	153	155	163	167	167			50	167
2.5	83	132	150	150	161	161	161			49	161
2.5	73	129	132	138	141	148	148			50	148
2.5	73	130	141	153	150	153	153			50	153
2.5	71	132	148	150	155	153	155			50	154
2.5	74	129	138	145	150	153	153			50	153
2.5	73	127	138	143	145	148	148			50	148
2.5	71	123	132	136	141	153	153			50	153
SUBJECT 5											
3.0	85	143	155	158	155	161	161			52	161
3.0	86	134	155	164	158	150	161	158		48	159.5
3.0	58	127	138	132	132	134	136			50	135
3.0	61	129	132	125	136	138	138			50	138
3.0	55	118	129	129	123	129	129			50	129
3.0	59	127	132	136	132	136	138			50	137
3.0	61	129	138	136	136	138	136			50	137
3.0	83mm	125	132	134	136	138	138			50	138

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Last Minute Revolutions	$\bar{X}$ Heart Rate
SUBJECT 6											
2.0	66	127	138	143	148	158	158			52	158
2.0	68	127	138	138	148	153	153			51	153
2.5	76	129	141	143	150	158	155			50	156.5
2.5	78	143	153	145	161	167	167			52	167
2.5	74	136	141	141	145	150	153			50	151.5
2.5	74	141	136	148	153	150	148			50	149
2.5	83	141	148	155	150	148	148			49	148
2.5	87	127	134	141	143	153	150			50	151.5

INDIVIDUAL RESPONSES TO THE ASTRAND-RYHMING TEST

GROUP II

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Revolutions	Last Minute $\overline{X}$ Heart Rate
SUBJECT 1											
3.0	80	117	118	127	134	136	141	145	145	51	145
3.0	78	130	145	143	155	148	150			50	149
3.0	73	118	130	132	141	141	143	143		50	143
3.0	62	108	120	123	125	125	125			50	125
3.5	88	127	134	136	134	138	143			50	140.5
3.5	96	129	132	136	141	143	143			50	143
3.5	90	115	129	127	132	132	138	138		50	138
3.5	82	122	132	141	153	150	150			50	150
SUBJECT 2											
3.0	71	132	145	141	141	145	141			50	143
3.0	70	122	130	129	138	132	141	143		51	142
3.0	89	136	145	143	143	145	145			51	145
3.0	68	122	132	134	132	134	134			51	134
3.0	70	123	123	132	138	132	132			51	132
3.0	67	122	129	125	129	129	129			50	129
3.0	87	122	132	130	127	132	132			50	132
3.0	102	132	138	143	145	143	141			50	142
SUBJECT 3											
2.0	107	154	155	164	161	164	164			50	164
2.0	100	138	145	145	155	155	155			50	155
3.0	88	145	158	158	167	173	173			50	173
3.0	69	143	150	158	170	173	173			50	173
3.0	79	138	153	161	167	173	173			50	173
3.0	73	138	150	161	167	170	173			50	171.5
3.0	87	145	161	161	167	173	173			50	173
3.0	80	132	153	155	167	176	176			50	176
SUBJECT 4											
2.5	68	145	155	164	167	170	170			49	170
2.0	74	141	150	155	153	155	155			50	155
2.5	76	148	155	153	158	161	164			52	162.5
2.5	78	141	150	158	153	158	155			50	156.5
2.5	73	150	150	155	155	158	158			50	158
2.5	79	155	161	158	161	161	161			53	161
2.5	83	145	145	145	143	153	155			51	154
2.5	87	132	141	150	153	158	158			50	158
SUBJECT 5											
3.0	66	120	130	136	134	141	141			52	141
3.0	64	114	117	115	125	127	132			49	129.5
3.0	92mm	106	113	115	117	120	123			50	121.5
4.0	82mm	125	134	143	155	155	155			50	155
4.0	82mm	130	143	155	164	164	167			50	165.5
4.0	66mm	129	138	150	153	153	158			50	155.5

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Last Minute Revolutions	$\overline{X}$ Heart Rate
SUBJECT 6											
4.0	61	118	132	145	145	155	155			50	155
2.0	78	122	145	148	153	153	158			56	155.5
3.0	83	143	155	150	167	155	173	173		49	173
2.5	98	141	143	145	145	150	150			50	150
2.5	78	132	136	136	141	145	145			50	145
2.5	66	130	134	136	143	138	138			50	138
2.5	73	132	122	125	129	134	129	132		50	130.5
2.5	78	136	138	132	138	145	143			50	144
2.5	87	129	132	136	141	141	148	145		50	146.5

INDIVIDUAL RESPONSES TO THE ASTRAND-RYHMING TEST

GROUP III

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Revolutions	Last Minute $\overline{X}$ Heart Rate
SUBJECT 1											
2.0	82	145	155	155	167	170	170			50	170
2.0	86	138	153	155	170	173	170			50	171.5
2.0	73	138	141	155	158	155	155			51	155
2.0	76	129	145	145	148	150	150			50	150
2.0	76	130	143	153	150	155	155			50	155
2.0	85	134	148	150	148	150	150			50	150
2.0	94	141	155	153	155	155	158			50	156.5
2.0	87	125	145	145	148	155	155			50	155
SUBJECT 2											
3.0	78	130	148	150	148	153	150			52	151.5
3.0	75	114	134	132	136	148	148			49	148
3.0	68	113	125	130	132	129	130			50	129.5
3.5	62	123	134	141	143	143	145			50	144
3.5	61	122	132	138	141	141	143			50	142
3.5	87	136	145	145	150	150	150			50	150
3.5	87	132	143	145	150	148	153	153		50	153
3.5	80	129	145	153	153	161	161			50	161
SUBJECT 3											
2.0	101	150	155	161	164	158	158			50	158
2.5	83	145	158	161	167	161	164			49	162.5
2.5	72	134	138	141	138	148	145			50	146.5
2.5	71	129	138	141	145	148	145			50	146.5
2.5	89	132	138	145	145	145	145			50	145
2.5	79	129	141	145	148	150	150			50	150
2.5	87	130	145	150	150	155	155			50	155
2.5	105	136	143	153	153	161	161			50	161
SUBJECT 4											
3.0	82	127	138	136	136	138	138			49	138
3.0	74	122	127	129	132	134	138			49	136
3.0	76	125	129	129	130	136	132	136		50	134
3.0	79	122	134	132	136	134	134			50	134
3.0	90	132	134	141	134	143	141			50	142
3.0	82	120	129	132	129	134	134			50	134
3.0	83	138	132	136	132	136	136			50	136
3.0	75	120	125	129	130	138	138			50	138
SUBJECT 5											
3.0	71	117	122	122	125	123	123			48	123
3.0	62	115	122	122	122	122	123			51	122.5
3.5	74	136	132	141	129	143	136	141		50	138.5
3.5	99mm	113	125	120	122	123	123			50	123
4.0	94mm	117	129	130	125	129	130			50	129.5
4.0	57	129	132	132	136	141	136	141		50	138.5
4.0	58	125	129	134	132	138	138			50	138
4.0	65	132	138	138	145	148	150			50	149

Resistance kp	Heart Rate Pre ex.	1	2	3	4	5	6	7	8	Last Minute Revolutions	$\bar{X}$ Heart Rate
SUBJECT 6											
3.0	62	107	115	115	120	127	129			49	128
3.0	61	117	125	129	123	120	130	136	132	50	134
3.0	57	107	105	108	117	111	117	123	118	51	120.5
4.0	89mm	120	130	130	134	145	148			50	146.5
4.0	60	132	145	143	145	153	155			50	154
4.0	87mm	125	130	134	143	145	145			50	145
4.0	85mm	115	129	130	136	136	141	141		50	141
4.0	79	129	141	138	141	143	145			50	144

PREDICTED MVO_2 - LITRES PER MINUTE

	Control	I(155)	II(140)	III(125)
Initial	3.4	2.9	3.4	1.8
	2.2	2.8	3.4	3.3
	2.5	2.5	1.9	2.0
	3.2	2.2	2.1	3.6
	3.3	2.9	3.7	4.6
	3.1	2.1	2.3	4.2
End of First Week	3.2	2.5	3.2	1.7
	2.3	2.9	3.4	3.2
	2.7	2.8	2.1	2.3
	2.7	2.3	2.1	3.7
	4.0	2.8	4.0	4.6
	3.3	2.1	2.4	3.9
2	3.3	3.3	3.5	2.1
	2.8	3.0	3.4	4.1
	2.1	2.9	2.5	2.8
	2.8	2.7	2.4	3.9
	3.9	3.8	4.7	4.2
	3.4	2.5	2.7	4.9
3	3.0	3.4	4.5	2.2
	2.2	3.5	3.9	4.0
	2.4	2.9	2.5	2.8
	2.9	2.6	2.5	3.9
	3.8	3.7	4.0	5.4
	3.3	2.3	2.8	4.4
4	3.5	3.8	4.1	2.0
	2.3	3.4	4.1	4.1
	2.4	3.2	2.5	2.8
	3.4	2.6	2.5	3.5
	3.6	4.2	3.6	5.5
	3.3	2.6	3.1	4.0
5	3.2	3.5	4.0	2.2
	2.1	3.4	4.2	3.7
	2.6	3.3	2.6	2.7
	2.8	2.6	2.5	3.9
	3.6	3.7	4.0	4.9
	3.4	2.7	3.4	4.5

PREDICTED MVO_2 - l/min. (continued)

	Control	I(155)	II(140)	III(125)
	3.4	3.5	4.3	2.0
	2.5	3.6	4.0	3.6
6	2.5	3.4	2.5	2.5
	3.4	2.7	2.6	3.7
	3.7	3.7	4.2	5.0
	3.4	2.7	2.9	4.7
	3.0	3.4	3.7	2.0
Six Weeks After	2.7	3.4	3.5	3.3
Termination of	2.6	3.0	2.5	2.4
Training Pro-	3.8	2.6	2.5	3.7
gramme	3.5	3.7	4.0	4.3
	3.7	2.6	2.8	4.5

PREDICTED MVO_2 SCORES

EXPRESSED IN MILLILITRES PER KILOGRAM OF BODY WEIGHT

	Control	I(155)	II(140)	III(125)
	36	44	40	35
	36	36	39	37
Initial	37	38	31	30
	44	36	32	45
	51	41	50	71
	35	37	34	49
	34	38	38	33
	38	37	39	36
End of	40	43	34	34
First Week	37	38	32	46
	62	40	54	71
	38	37	36	46
	35	50	41	41
	46	38	39	46
2	31	45	41	42
	38	44	36	49
	60	54	64	65
	39	44	40	58
	32	52	53	43
	36	45	45	44
3	35	45	41	42
	40	43	38	49
	58	53	54	83
	38	40	42	52
	37	58	48	39
	38	44	47	46
4	35	49	41	42
	47	43	38	44
	55	60	49	85
	38	46	46	47
	34	53	47	43
	34	44	48	41
5	38	51	43	40
	38	43	38	49
	55	53	54	75
	39	47	51	53

PREDICTED MVO_2 - ml/kg/min. (continued)

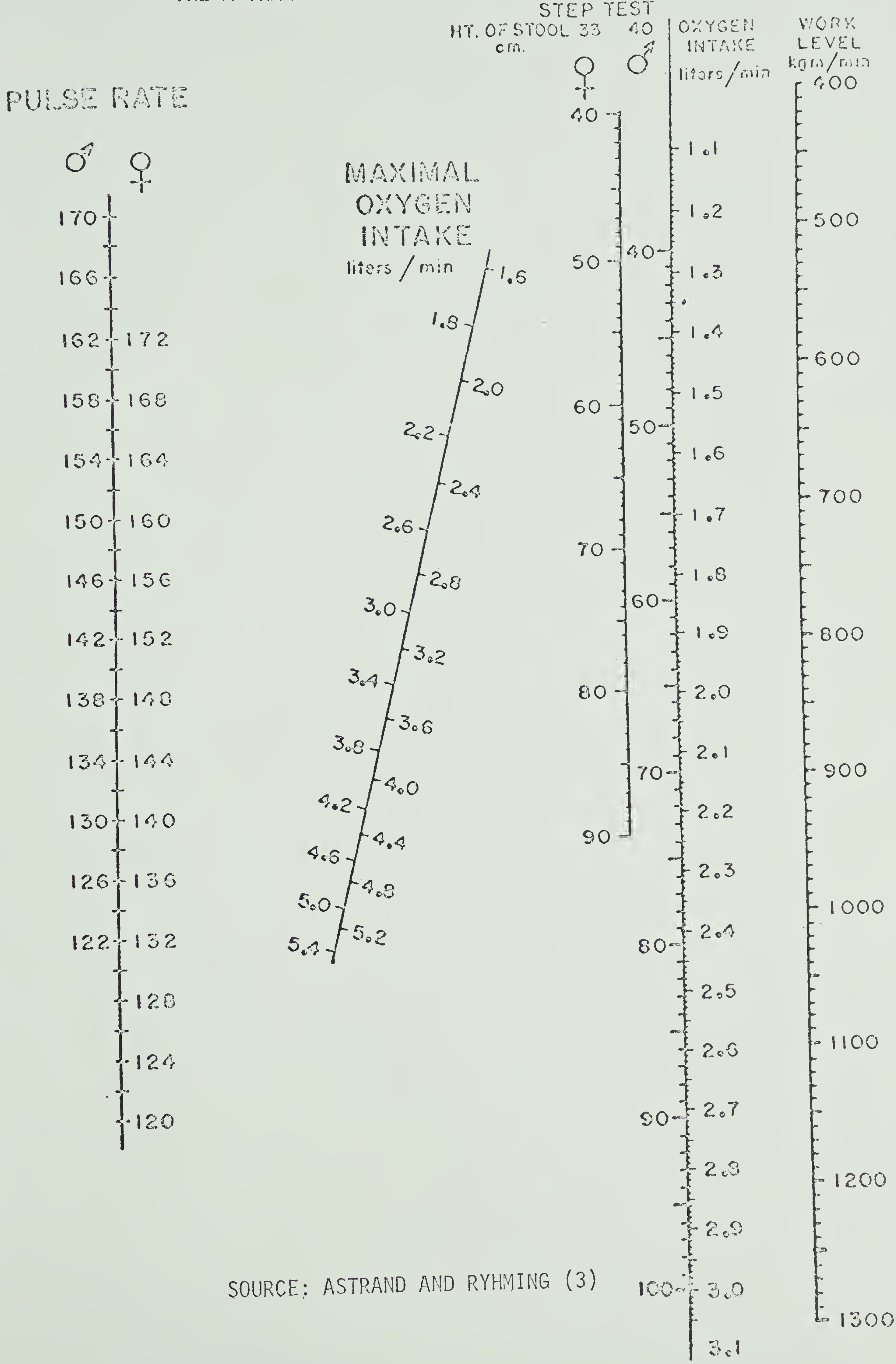
	Control	I(155)	II(140)	III(125)
	36	53	51	39
	41	46	46	40
6	37	52	43	37
	47	44	39	46
	57	53	57	77
	39	47	43	55
	32	52	44	39
Six Weeks After	44	44	40	37
Termination of	38	46	41	36
Training Pro-	52	43	38	46
gramme	54	53	54	66
	42	46	42	53

INDIVIDUAL MEAN HEART RATES AND CORRESPONDING

WORK LOADS UNDER CONDITIONS OF TRAINING

	GROUP I		GROUP II		GROUP III	
	H.R.	W.L.	H.R.	W.L.	H.R.	W.L.
	155.8	2.5	142.3	2.5	126.6	1.0
Beginning	156.3	2.4	140.8	2.8	121.4	2.3
at end of	154.4	2.0	142.9	2.0	126.3	1.3
2nd Train-	155.2	2.0	140.3	1.6	127.1	2.3
ing Week	151.3	2.5	141.1	2.6	122.1	2.8
	153.0	2.1	142.2	2.2	124.6	2.4
	155.6	2.8	138.2	2.9	124.7	1.3
	154.9	2.9	140.4	2.8	123.6	2.5
3	153.9	2.3	142.4	1.9	126.9	1.4
	155.7	2.3	140.6	1.9	125.7	2.2
	152.3	3.0	141.2	2.8	123.1	2.8
	151.2	2.2	141.8	2.2	124.4	2.6
	153.9	2.9	140.3	3.1	126.7	1.2
	156.4	3.1	140.6	2.8	126.4	2.6
4	154.4	2.5	141.2	1.8	128.4	1.5
	156.5	2.4	141.0	2.1	127.4	2.3
	154.9	3.1	142.5	2.9	125.6	3.2
	154.4	2.3	143.3	2.4	125.9	2.7
	156.0	2.9	143.1	3.1	126.8	1.2
	155.2	3.1	142.7	2.9	126.6	2.6
5	150.2	2.7	142.4	1.9	126.3	1.4
	156.3	2.3	141.1	2.1	125.8	2.3
	155.4	3.1	141.4	2.9	125.3	2.9
	156.1	2.4	141.9	2.3	124.8	2.9
	155.2	2.9	140.7	3.2	126.7	1.3
	153.6	3.2	139.4	2.9	126.5	2.6
6	150.2	2.7	140.5	2.1	127.9	1.4
	152.3	2.5	141.7	2.1	126.2	2.6
	152.6	3.2	139.0	3.1	126.2	2.9
	154.9	2.5	141.4	2.5	125.0	2.8

THE ASTRAND-RYHMING NOMOGRAM



SOURCE: ASTRAND AND RYHMING (3)